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by

D.S. Richardson and K.B. Robertson

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Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

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1. INTRODUCTION

The north Nordeste region of northeast Brazil (figure 1) has a well defined rainfall season, predominantly in the months of March to May. Drought in the region has a major effect on the local economy. Much work has been done on the rainfall variability of the Nordeste (for a review, see Hastenrath, 1991, 302-309) and a number of techniques have been developed to forecast seasonal rainfall anomalies (Ward and Folland, 1991; Hastenrath and Greischar, 1993). The potential use of the Met Office Unified Model (UM) in providing seasonal rainfall forecasts for this region was demonstrated in a set of 4 multi-decadal simulations run using observed sea-surface temperatures (Bevan et al, 1993). This note describes a real-time forecast for the 1994 rainfall season made using a revised version of the UM. The integration forms part of a larger investigation into dynamical seasonal forecasting which is underway at the Met Office. This work will be carried out running the UM on Dec Alpha workstations; the Brazil forecast described here is one of a number of seasonal integrations being run on the Cray to compare Cray and workstation versions of the model.

2. MODEL AND BACKGROUND DATA

The initial encouraging UM results were derived from the 'Climate of the 20th Century' (C20C) project being undertaken at the Met Office (Bevan *et al.*, 1993). These were run using the '3.1 frozen physics' version of the UM at climate resolution (2.5° lat x 3.75° long). Observed SST and sea-ice fields were prescribed from the Met Office Global sea-Ice and Sea Surface Temperature dataset (GISST). Four integrations were run from 1949-1993, initialised from different atmospheric analyses. Although large differences between integrations were noted in many regions even on decadal timescales, all four produced consistent, and skilful, simulations of Nordeste rainfall. Note that these rainfall data are standardised values: the model rainfall has been standardised using the 30-year mean and standard deviation from years 1951-80 in the simulations; observed values were standardised using observed climate statistics. This was necessary because the model had a significant dry bias over the north Nordeste, represented by 2 gridpoints in the model at 37.5°W,5°S and 41.25°W,5°S. These two gridpoints are chosen as those closest to the stations of Quixeramobim and Fortaleza (figure 1) which are the two stations currently used to verify the Met Office statistical forecast (Ward and Folland, 1991).

The version of the UM used for seasonal research will be the 'revised frozen physics' version 3.2 (RF32). The main differences from that used in the C20C integrations are in the cloud scheme and the moisture diffusion. A number of other changes and minor corrections have been made. While no multi-annual integrations with observed SSTs have yet been made, integrations using climate SSTs indicate substantial differences between the two versions. RF32 is generally drier than the previous version in March-May over the tropical Atlantic, Indian and west Pacific oceans and wetter over South America, central Africa and Indonesia (figure 2). Averaged over the season (March-May) and over the 2 Nordeste gridpoints, RF32 version is 33% wetter (table 1). This is encouraging given the substantial dry bias of the C20C version (approx 25% too dry - N Ward, personal communication).

3. CALIBRATION OF THE MODEL

Because of the substantial differences between model versions noted above, two seasonal simulations were made to calibrate the RF32 model used for the 1994 forecast. Integrations were made for the 1987 (dry) and 1989 (wet) rainfall seasons. The atmospheric initial conditions were the ECMWF analysis for 00Z on 1 January and the observed GISST sea-ice and SSTs were used.

3.1 General features

The seasonal mean (Mar-May) difference in PMSL between the 1987 and 1989 simulations shows the characteristic signature of the Southern Oscillation, with the dipole between the Australasian/Indonesian region and the eastern South Pacific (figure 3a). The model has correctly simulated the difference between the negative phase of the SO in 1987 and the positive phase in 1989. The positive pressure difference in the Caribbean and North Atlantic and negative differences in the South Atlantic agree well with observed PMSL differences between wet and dry Nordeste rainfall years (Hastenrath 1984).

A number of characteristic features can also be seen in the seasonal rainfall differences (figure 3b). The large negative differences over the equatorial and positive differences over parts of Indonesia and Australia reflect the rainfall differences in these regions experienced in El Nino and anti-El Nino years (Ropelewski and Halpert, 1987, 1989). The increase in rainfall in the tropical South Atlantic, extending from NE Brazil towards equatorial Africa agrees with the enhanced cloudiness observed in wet Nordeste years (Hastenrath, 1984). All these rainfall differences correspond to the main features noted by Mechoso and Lyons (1988) who have also compared GCM simulations for a wet year (1984) and a dry year (1983, El Nino).

The general patterns described above indicate that the RF32 model simulations have correctly distinguished the atmospheric behaviour during the 1987 warm event from that of the 1989 cold event. The pressure and rainfall features associated with wet and dry Nordeste years have also been correctly simulated.

As mentioned in section 2, there is as yet no climatology for RF32 using observed SSTs. However, to give an indication of forecast rainfall anomalies the rainfall climatology is taken from the 10-year integration of RF32 with climatological SSTs. The high rainfall in the equatorial Pacific, low rainfall over Indonesia and Australasia, and low rainfall in the Nordeste and tropical South Atlantic in the 1987 simulation show up well as anomalies from this climatology (figure 4a). The simulation for the wet Nordeste year of 1989 shows positive anomalies over part of the Nordeste and in the tropical South Atlantic, with associated negative anomalies over the Guyanas (figure 4b). These correctly simulated anomaly patterns suggest that it is reasonable to use this climatology as at least a qualitative basis for deriving forecast rainfall anomalies for the Nordeste.

3.2 North Nordeste rainfall

In the previous section it was shown that the simulations for 1987 and 1989 correctly reproduced features typical of dry and wet Nordeste years respectively. The model produced negative rainfall anomalies over NE Brazil for 1987 and positive anomalies over much of the region for 1989. The model rainfall for the two north Nordeste gridpoints is now compared with that from the ensemble mean of the C20C integrations and with observed values from Fortaleza and Quixeramobim. Anomalies are from the corresponding model or observed climatology; for C20C, this is a 30-year climatology using years 1951-81 of the C20C simulations.

In absolute terms, the RF32 simulation is substantially wetter (by 50%) in 1987 than C20C (table 2a); however, when expressed as anomalies from the respective climatologies, the RF32 simulation is drier than normal (84%), relatively drier than the C20C simulation (90%) and closer to the observed rainfall anomaly, approximately 70%. Both simulations for 1989 are substantially wetter than the corresponding 1987 runs, by 130% for C20C and by 120% for RF32 (table 2b). Relative to climatology, the RF32 rainfall is near normal, whilst that of the C20C simulation is above normal, closer to the observed value of 130%. The near average rainfall for these two gridpoints in the RF32 simulation seems to be a localised feature, with the positive anomalies in the south of the region and in the equatorial Atlantic failing to reach the northern part of NE Brazil.

4. FORECAST FOR 1994 NORTH NORDESTE RAINFALL

The forecast for March-May 1994 was initialised with the Met Office analysis for 00Z on 1 January 1994. Observed monthly-mean SST and sea-ice fields for December 1993 and January 1994 were used. For February to May, the observed SST anomalies for January were persisted; sea-ice fields were reset to climatological values from February onwards. A major feature of the seasonal-mean rainfall is the large area of above average rainfall in the tropical South Atlantic which extends inland across the Nordeste and an associated area of below average rainfall to the northwest (figure 5).

Above average rainfall is forecast for north Nordeste each month (table 3), with a seasonal average of 129% of normal rainfall. This corresponds well with the Met Office statistical north Nordeste Brazil forecast which is for March-May rainfall substantially above average (approximately 130%- N Ward, personal communication).

5. CONCLUSIONS

The potential use of the UM in forecasting rainfall for the north Nordeste region of NE Brazil was demonstrated in the 'Climate of the 20th Century' integrations. There were two main conclusions:

1. Interannual variability of north Nordeste rainfall was successfully simulated.
2. There was no significant difference in this region between runs with different atmospheric initial conditions.

The version of the UM which is being used for research into seasonal forecasting is different in a number of respects from that used in the C20C study. It is not surprising that it may have a different precipitation climatology. No climate has been produced using this version of the UM with observed SST forcing, so the best approximation available is a 10-year climate run using climatological SSTs. This is substantially wetter over many areas, including the Nordeste, than a similar climatology produced using the previous version (as used in the C20C).

It must be noted that the climatology of the model using real SSTs may differ from that used here which was derived from an integration using climatological SSTs. Bearing this in mind, relative to this RF32 climatology, a simulation for the 87 rainfall season produced drier than average conditions, as occurred. For 89, simulated rainfall was near normal for the two gridpoints used, although the more general pattern suggested a wet Nordeste year as occurred. The 94 forecast is wetter than both the 87 and 89 simulations, and well above the 3.2 climate (130%). Qualitatively, the result indicates that 1994 will be a wet year. The magnitude of the persisted SST anomalies may affect the predicted rainfall; a decrease in SST anomaly during the spring may lead to less rainfall than predicted, although still probably above normal.

Results from the C20C experiment have shown integrations to be sensitive to the initial conditions in many regions of the tropics. NE Brazil was found to be one of the regions least sensitive to analysis differences, much of the variance in model rainfall over NE Brazil being linked to the SST field imposed on the model (Bevan *et al.*, 1993). Nothing can be deduced at this stage about the variation of the RF32 forecast with initial conditions. However, the simulations of 87 and 89 correctly captured the main features of those years. If there is a substantial dependence on initial conditions then in both cases we were fortunate in choice of initial conditions. We must assume that, as with the previous version, the Brazil region is relatively insensitive to changes in initial conditions.

ACKNOWLEDGEMENTS

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	Frozen 3.1			Revised frozen 3.2			
	A	B	mean	A	B	mean	% of 3.1
Mar	9.66	3.50	6.58	10.68	6.11	8.39	128
Apr	8.78	4.21	6.50	9.84	6.83	8.34	128
May	4.06	2.82	3.44	5.72	4.95	5.34	155
Mar-May	7.5	3.6	5.5	8.7	6.0	7.3	133

Table 1. Rainfall rates (in mm/day) for two model gridpoints representing north Nordeste (A:37.5E, 5S and B:41.25W, 5S) for 20-year mean of frozen 3.1 integration and 10-year mean of revised frozen 3.2 integration, both integrations with climatological SSTs.

	C20C (3.1)		RF32 simulation			
	mean A & B	% of climate	A	B	mean	% of 3.2 climate
Mar	5.79	95	10.63	7.64	9.14	109
Apr	5.23	93	6.95	4.33	5.64	67
May	1.89	70	4.48	2.57	3.53	66
Mar-May	4.3	90	7.4	4.9	6.1	84

Table 2a. Rainfall rates (in mm/day and as percentage of corresponding climate) for two model gridpoints representing north Nordeste (A:37.5E, 5S and B:41.25W, 5S) for March-May 1987 from climate of 20th century runs (mean over 4 integrations) and revised 3.2.

	C20C (3.1)		RF32 simulation			
	mean A & B	% of climate	A	B	mean	% of 3.2 climate
Mar	6.59	108	10.83	6.52	8.68	103
Apr	6.33	113	8.13	5.67	6.90	83
May	3.97	145	5.01	6.56	5.79	108
Mar-May	5.62	117	7.99	6.26	7.35	97

Table 2b. As table 2a but for March-May 1989.

	Revised frozen 3.2 forecast			
	A	B	mean	% of 3.2 climate
Mar	10.54	7.49	9.02	108
Apr	11.66	8.69	10.18	122
May	9.77	8.56	9.17	170
Mar-May	10.6	8.2	9.5	129

Table 3. Rainfall rates (in mm/day and as percentage of RF32 climate) for two model gridpoints representing north Nordeste (A, B) for March-May 1994 revised 3.2 seasonal forecast.

FIGURE CAPTIONS

Figure 1. Location map of the north Nordeste. The stations of Fortaleza and Quixeramobim, used to verify the Met Office statistical forecasts are marked.

Figure 2. Difference between March-May seasonal mean rainfall climatologies for the 'frozen 3.1' and 'revised frozen 3.2' versions of the Unified Model. Differences are contoured at 1 mm/day intervals with solid lines indicating that 3.2 is wetter and dashed lines that 3.2 is drier than 3.1.

Figure 3. Seasonal mean (March-May) differences between the 1987 and 1989 RF32 simulations for PMSL (a, in hPa) and rainfall (b, in mm/day). Solid contours indicate higher values, and dashed contours lower values, in 1989 than 1987.

Figure 4. Seasonal mean (March-May) rainfall for (a) 1987 and (b) 1989 as anomalies (mm/day) from the RF32 model climatology. Solid contours indicate positive anomalies and dashed lines negative anomalies.

Figure 5. Seasonal mean (March-May) rainfall forecast for 1994, as anomaly (mm/day) from the RF32 model climatology. Solid contours indicate positive anomalies and dashed lines negative anomalies.

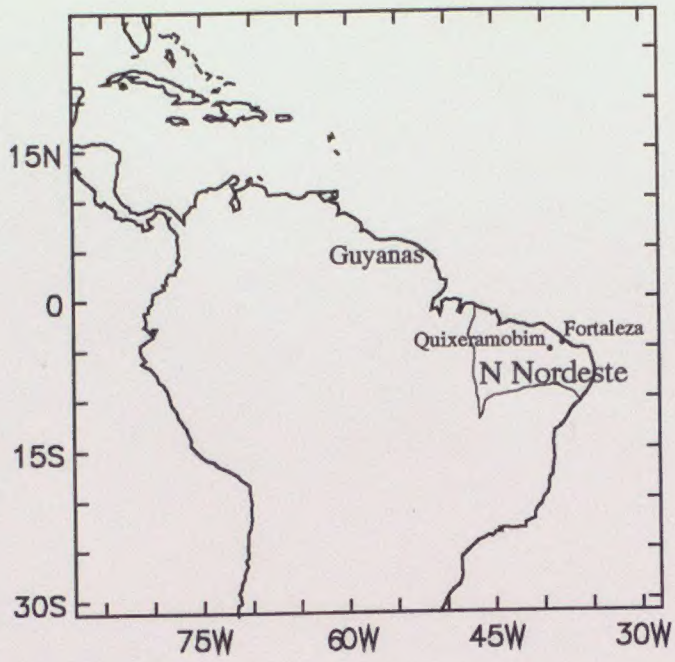

Figure 1. Location of north Nordeste.

Figure 2. Model rainfall climatology, Mar–May. RF32 – frozen 3.1

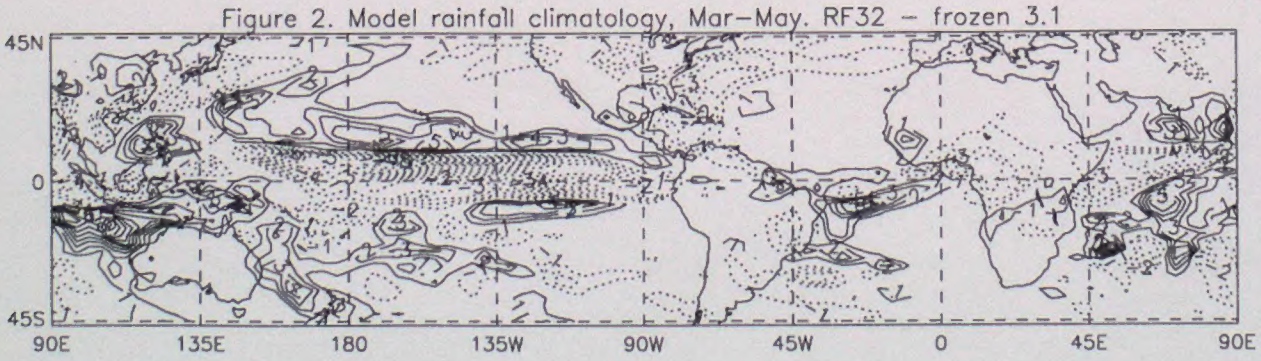

Figure 3a. Model PMSL. (Mar–May 89) – (Mar–May 87)

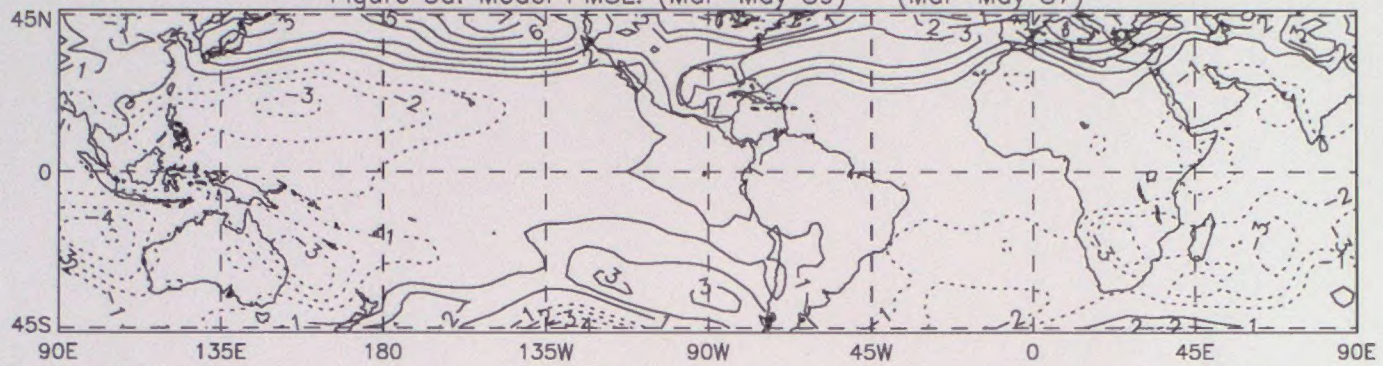

Figure 3b. Model rainfall. (Mar–May 89) – (Mar–May 87)

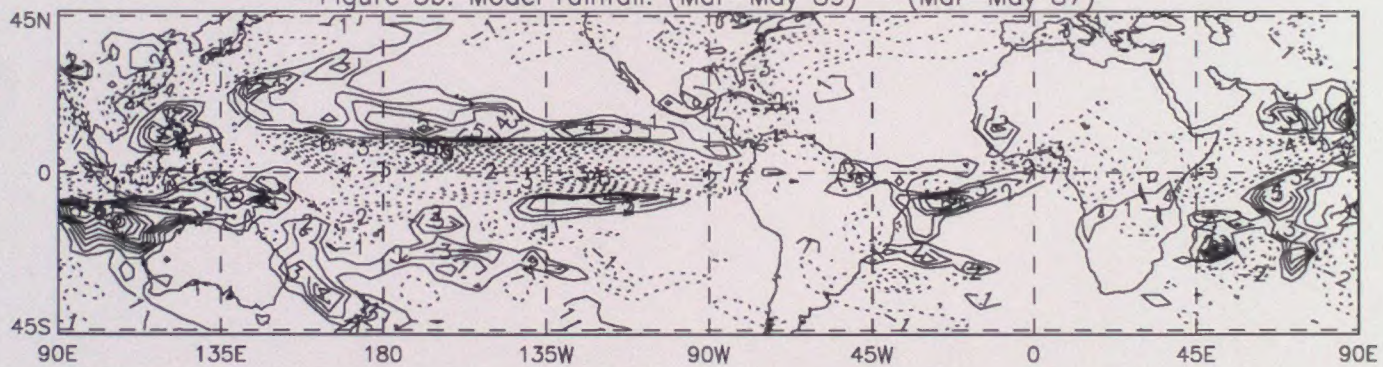

Figure 4a. Model rainfall, Mar–May 87 (mm/day, anomaly from model climate)

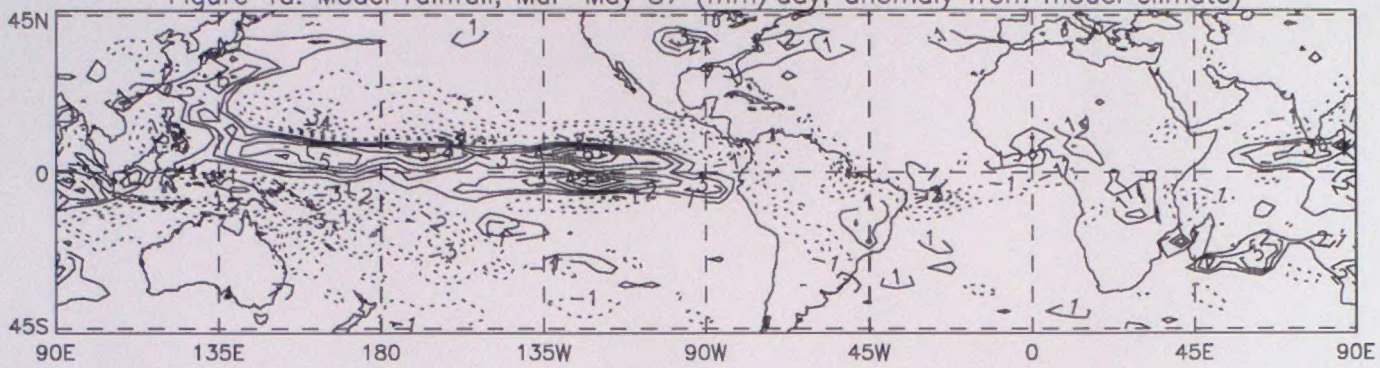

Figure 4b. Model rainfall, Mar–May 89 (mm/day, anomaly from model climate)

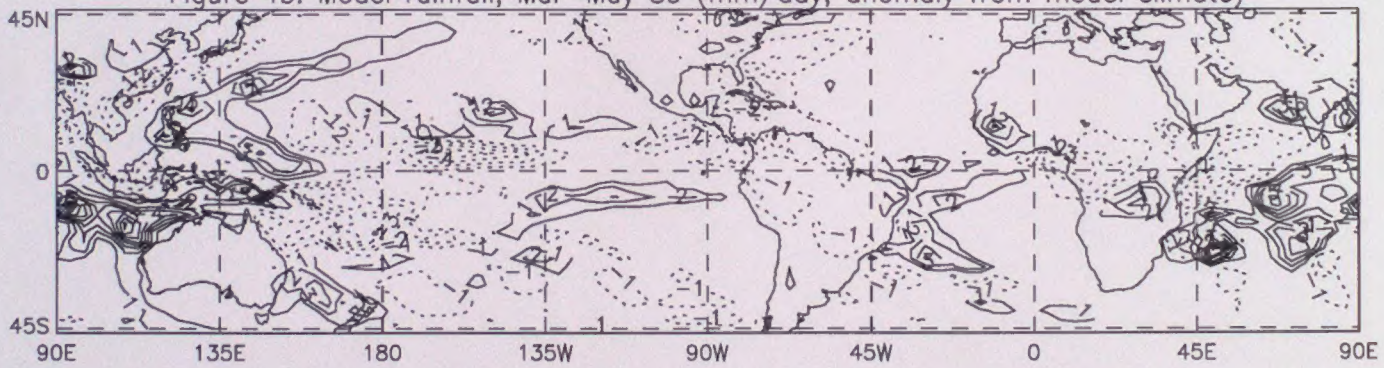
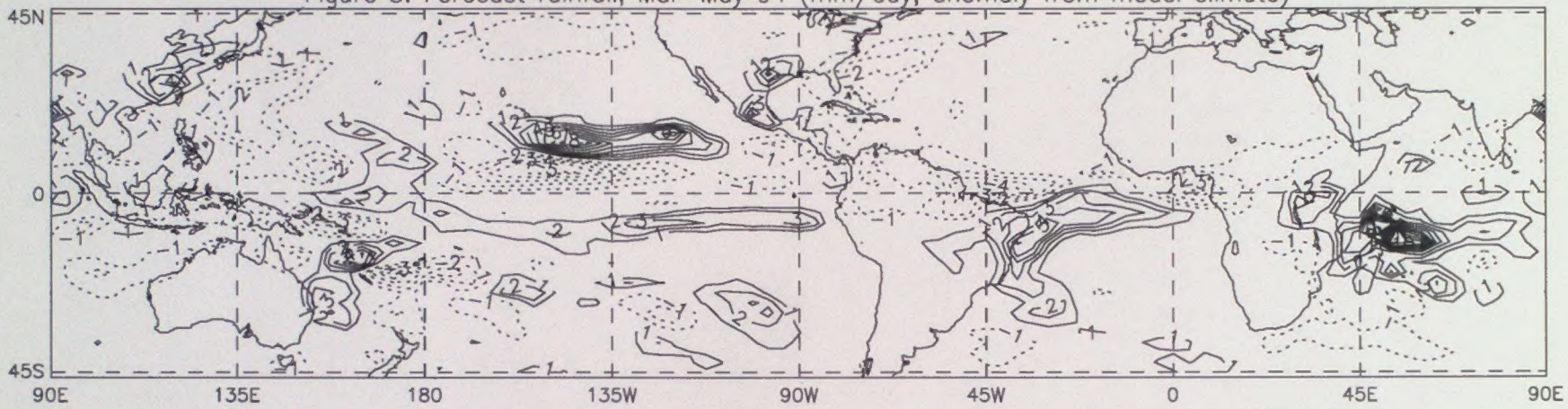
Figure 5. Forecast rainfall, Mar–May 94 (mm/day, anomaly from model climate)